A NEW THEORY of the Ebbing & Flowing of the SEA

1816.

Sloat

A

NEW EXPLANATION

OF THE

EBBING AND FLOWING

OF

THE SEA,

UPON THE

PRINCIPLES OF GRAVITATION.

Daniel Wm. Campbell. 1816.

By S. BENNETT.

Baltimore Auction

Humanum est errare.....Suum cuique tribuito.

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INTRODUCTION.

Amidst the pursuits of business, and the bustle of life, there are few men who are unwilling to give some moments to the gratification of curiosity, and the attainment of liberal information. The general diffusion of knowledge is such, that a man would blush to be found totally ignorant of every thing, except the particular business in which the cares of life engage him. Who would be ignorant in geography, like the Spaniard of Monte Viedo, who asked in how many days he could *ride* to England; or as the Hottentot, who went upon the mountain to lay hold of the moon by her horns, and bring her down? In this age of mechanical invention, who would be unacquainted with the first principles of *Mechanics*, which never vary? Amongst the *Greeks*,

it was thought shameful for a person to be ignorant of the properties of the triangle, square and circle; yet what use could that simple people have for such knowledge, compared with the present generations. The pursuit of money is now the universal passion, and human knowledge esteemed nearly in proportion as it conduces to the attainments of it; yet there are many sublime truths, which, though not immediately profitable to the man of business, have a value of a different and more important kind. Such are all the sublime truths of Natural Philosophy or Physics, and of Astronomy: these lead us to a view of the whole system of the universe, and to connect with it the little globe which is our present habitation: these lead us in a particular and especial manner, to turn towards its author with humble and grateful hearts.

The career of Chemistry has opened a wide field of information, and the progress of *minute philosophy* connecting itself with the arts of life, has been truly astonishing. The great system of the universe was demonstrated by Newton. The earth was connected by the law of gravita-

tion with the heavenly bodies, but more particularly with the sun and moon, by whose influence the ocean is agitated, and the tides produced.

Of late years, however, the mode of explaining this phenomenon, has been very justly questioned, and for this reason; namely, *that the phenomenon or effect, does not agree with the cause assigned.*

The author having traversed the torrid zone, has had occasions to observe all the various modifications of which the ocean is susceptible, from the influence of the sun and moon, and has thence deduced (as he believes) the true theory or explanation of the ebbing and flowing of the sea, which he offers to the curiosity of mankind.

The observations which he has been enabled to make in other parts of the world, all tend to confirm this new mode of explanation, and he is still in pursuit of others for the same purpose. He invites the inquisitive to confirm or to refute it with candor and impartiality.

The ebbing and flowing of the sea, so useful to mankind, is a phenomenon which has justly excited wonder and admiration in all ages, and ought no less to excite gratitude to the all wise and beneficent architect of the universe.

The flowing of the tide from the sea into the mouths of rivers, causes their currents to stop, to turn, and run backwards far inland, with such an accumulated body of water, as is sufficient to bear the deep laden ship to the crouded mart.

The wealth, the splendor, the strength, the happiness of nations, are more or less connected with this familiar and regular phenomenon; the *cause* or *causes* of which, it is the business of this little tract to investigate and explain.

That the earth is only one of the planetary bodies revolving about the sun, is now universally admitted, and that these bodies have an effect on each other, known by the names of gravitation and attraction, is also admitted. The whole doctrine has been established on demonstration by the in-

comparable Sir Isaac Newton, in such a manner as is never likely to be called in question.

Although the general principle of gravitation has been so firmly established, it may yet be possible, that in the application of that principle to account for particular phenomena, there may have been some error; if then I apply the principle of gravitation to account for the ebbing and flowing of the sea, in a different manner from the present received one, it will only be a confirmation of, and not a contradiction to, the general doctrine of gravitation.

Every now and then, indeed, we hear of something under the name of *Newton refuted;* but when we come to examine what it is, we find nothing but some thoughtless trash, from persons altogether destitute of mathematical information.

Let me therefore be distinctly understood, that I mean only to apply the principle of gravitation in a different manner from what has hitherto been done, to account for and explain the particular phenomenon of the tides; and that this new way

of explaining that phenomenon, will confirm in a most remarkable manner, the general doctrine of gravitation, as established by Sir Isaac Newton.

After meditating upon this subject for more than ten years, I find myself at length compelled to lay the result before the world. The objections to the Newtonian account of the tide, stated by *Sullivan*, *St. Pierre* and others, but more especially the disagreement betwixt the theory and actual phenomenon, first led me to think seriously upon it. I now deliver these thoughts, which are the result, to the world, believing them to be true; if they are otherwise, let those who are able point out their falsehood; as for those who are not able, let them be silent.

The praise or censure of common critics can have but little influence on questions of this nature. I am well aware before what awful judges I stand. Let them measure out justice by the standard of truth, their mercy is out of the question.

New-York, March 10th, 1816.

THE

EBBING AND FLOWING

OF

THE SEA, &c.

CHAP. I.

CONTAINS SOME PRELIMINARY MATTERS.

1. Most of our first ideas want correction. It is somewhere said, that the ancients believed the sea was made to rise and fall, by the respiration of a great fish; this was well enough for the poets: nor was there a much better idea on the subject, as far as I can find, for many ages. What account Aristotle, who accounted for every thing, gave of the matter, I cannot tell, nor shall I go out of my way to inquire.

2. It was discovered that the rising of the waters of the sea accompanied the moon, and it was necessarily inferred, that she must somehow or other be the cause. Kepler was the first, I believe, who gave any thing like a rational conjecture about the tides, asserting that the moon gave an impulse in her presence, which impulse produced by its reaction, another in her absence. I do not find that this idea was followed by Kepler, so as in a satisfactory manner to account for all the various appearances of the phenomenon. Then came Newton, who demonstrated every thing in so subtile and profound a way, that if he committed any error, it was equally hidden from himself, and all who have since followed him.

3. It may not be amiss in this place, to say something concerning the method of mathematicians, and the certainty of their conclusions. They begin with a few well known principles under the name of *axioms;* and by the help of these, others are inferred, which were before unknown, and so on from one inference to another, never using any thing but what was at first self-evident, or since by their help proved to be true, or conform-

able to those self-evident principles or axioms, or somehow or other growing as a necessary consequence out of them: by this precise and careful method, this mode of proceeding has been dignified with the name of *demonstrative science*, and that most deservedly, since no other branch of human knowledge admits of a like degree of certainty; and as the mathematical sciences enter into, and as it were, lay the very foundation of all the important arts of life, they have always been, and no doubt always will be, entitled to the highest consideration of mankind.

4. It has, however, been objected by some, that the mathematical sciences are imperfect, because the mathematician can proceed just as well upon *false data* as upon *true*, and this is certainly the case; but it may be doubted whether this is an imperfection, and not rather the greatest perfection his art can have, his business being only to deduce *consequences* from self evident principles. It is no fault of the art, then, that wrong consequences should be deduced from wrong principles, which ought not to have been assumed; the only care to be taken is, that no *data* be assumed

which is not *true*. Suppose, for example, I was to say for data, that 2 and 2, instead of making 4, make 5, thus : $2+2=5$. Now nothing hinders me from working this equation just as if it were true. Suppose I would add 6 to both sides, then it will stand thus: $2+2+6=5+6$, or $10=11$. If I would multiply this last equation, suppose by 20, then $200=220$; and so on through any number of operations.

It may be seen that the *error* is, in this last equation, twenty times greater than in the first; and if the operation be reversed, dividing by 20, the second equation will be produced $10=11$; and subtracting 6 from each side, then 4 may be inferred to be equal to 5, agreeably to the false supposition. There is no fault here in the art itself, for it *proceeded correctly upon the supposition*. We must be careful to suppose nothing but what is true; and then we may rely upon all the deductions which we fairly make upon it. If I say that any quantity represented by a is equal to two other quantities represented by b and c, or $a=b+c$, then however I may increase or diminish one side of the equation, if I do the same by

the other, I shall never destroy it, or run the smallest risk of drawing a false conclusion.

But if there should happen to be an error in the supposition itself, namely, that $a=b+c$, and this error should be of such a nature that all mankind fall into it, it would seem very difficult to correct it; because, being in the data itself, and that data being false, and yet universally admitted as true, how is it possible in such a case to find out the error? It can only be done by thinking differently from all mankind, which is a task in itself infinitely difficult.

5. If we would detect any error in the whole body of the mathematics, or mathematical philosophy, we must expect it only in the principles or data, for it is upon these the whole superstructure is raised; and this may appear to be correct and fair, although some error may exist in the data or first principles. And the same observation applies to the laws of motion, and to the rules of reasoning or philosophizing, as they are called, which I shall here set down, because we must have an eye to them constantly in the following

inquiry. I shall shew hereafter, that a false supposition with respect to the moon's power of of attraction, led Sir I. Newton to adopt the theory which he left of the tides, and which misled him and all who have followed him upon that subject.

6. The first rule is—Not to admit more *causes* of natural things, than such as are *true*, and sufficient for explaining their phenomena.

7. Rule 2. Natural effects of the same kind, have the same causes.

8. Observations on the foregoing rules.

There is some danger of leaving out efficient causes, by a desire to account, according to the first rule, for a given phenomenon, by the agency of one cause, or following the rule by the fewest possible. We ought not to attempt to account for any natural phenomenon by the agency of one cause, if more than one equally claim to be admitted. Two causes can always produce a given effect, more easily than one singly; and if one of

them can he shewn to be insufficient to produce the effect, the other, or some other, must be admitted.

An effect may result from one or more causes, and it is of the greatest consequence to distinguish whether the cause is single or compound. A single cause, on the contrary, can never produce but one effect, and that effect will be uniform and proportionable to the cause; if the cause varies, the effect will vary with it, and in the same proportion.

Moreover, the manner of acting must not be overlooked, since motion may be produced in bodies more easily in one direction than in another; thus it requires less force to move a body sideways, than to lift it up perpendicularly; and this truth will appear presently to be of the greatest consequence.

It may yet further be observed, with regard to cause and effect, that the true cause will ever be just, adequate, and proportionable to the effect and no more; in any case, if a disagreement

or incongruity can be shewn betwixt them, we may be sure the cause is not rightly assigned.

9. The laws of motion are as follows :

Law 1. All bodies continue in a state of rest, or of uniform motion in a right line, till made to change their state by some external force.

Law 2. The change of motion is proportional to the force impressed, and that change is produced in the same direction or right line in which the force acts.

Law 3. Action and reaction are equal, but with opposite directions.

It is said that all actions of bodies upon one another conform to these laws, and as far as we are acquainted with the actions of bodies on each other, they do do so; but when we apply them to those actions of bodies upon one another, with which we are *not acquainted,* as gravity, then those laws become liable to objection; as for example : in a body falling to the earth by its gra-

vity, whether the impelling force be *internal* or *external ;* whether it resides in the earth, or in separated falling matter itself, no mortal man, I believe, can tell ; and further, if it resided in the earth, small bodies ought to fall with a greater celerity than large ones, to preserve an equal momentum, according to the ordinary mechanical powers, with which, however, the law of gravity seems to have no connexion.

10. But to return to our subject : I shall conclude this preliminary chapter, by giving a table of the rise of the waters of the sea, by the joint influence of the sun and moon at the full and change ; and though I am sensible these observations, taken from ordinary books of navigation, are not so exact as could be wished, yet they will serve my purpose, as I intend only to use them in a general way.

I have selected only a few places on each shore of the Atlantic Ocean, and those as much out of the influence of local circumstances as I could. In this respect it is to be wished that they were still more so.

A TABLE,

Shewing the perpendicular rise of the tide at the undermentioned places, with the hour at Full and change of the Moon.

	F.	H.	M.
Halifax and Nova Scotia generally	8	7	30
Boston,	12	11	30
New-York,	5	8	54
Rhode Island,	5	7	37
Bermuda,	5	7	0
Charleston,	6	7	0
Jamaica, 10 or 12 in.			
Mouth of the Amazon River, under the line,	*		
Shetland rises	6	10	30
North end only	5		
The Orkneys,	8	10	30
The west Coast of Ireland,	11		
Coast of Portugal,	10	2	30
Madeira,	7	12	4
Port Praya, Cape de Verdes,	5	6	0
Cape St. Mary, near the mouth of the River Gambia,	2½	10	30
Bight of Benin, *in the rivers* 6 feet but out at sea	4 & 5		

* No tide at the mouth of the Mississippi, nor generally in the upper part of the Gulf of Mexico, consequently there cannot be much at the mouths of the Oronoko and Amazon.

The tides are better known on the coast of South America from the line southward; thus at Bahia and Rio de Janeiro, they are 4 and 5 feet; at the River Plate 6, and some say 7—but at the Cape of Good Hope the rise is only from 3 to 5 feet, according to the circumstances of variable winds. At the small islands of St. Helena, Ascension and Tristan de Cunha, there is very little tide. At the Falkland Islands 6 or 7 feet.

According as local circumstances vary, so will the tide vary in different places; thus out in the ocean the tides come on sooner, and do not rise so high as at places where by the formation of the land, the water is accumulated and pent up, as in the Bristol Channel, and the Bay of Biscay, where it accumulates so much as to rise to an extraordinary height; all these local circumstances I wish to avoid as much as possible, and endeavor to discover some general principles for the ocean itself.

11. Now in casting one's eyes over the foregoing little table it appears, first, that the tides rise higher in the temperate than in the torrid

zone, contrary to the present theory of the tides; secondly, that the tides do not appear to rise so high on the shore of America as on that of Europe and Africa; thirdly, that the hour of high water appears to be different, and generally later on the American shores, even at places but little influenced by local circumstances.

The following observations are from Captain Cook's third voyage, and from Bligh's voyage to the South Sea.

FRIENDLY ISLES.

"At these islands the tides are *more considerable* than at any other of Capt. Cook's discoveries in this ocean, that are situated *within either of the tropics.*" "In the channels between the islands, it flows near tide and half tide; and it is only here and in a few places near the shore *that the tide is perceptible,* so that we could only guess at the quarter from whence the flood comes. At Annamooka it is high water near 6 o'clock, on the full and change of the moon, and the tide rises and falls about 6 feet. At Tongataboo the

tide rises and falls 4 feet three quarters on full and change days, and three feet and a half at the quadratures."

Lat. of Annamooka, 20, 15, S.
Tongataboo, 21, 8.

At Matavia, Otaheite, the tide seldom exceeds 10 or 12 inches, lat. 17, 29, S.

At Port Jackson, 6 feet spring and 4 feet 6 inches neap.

Pelew Islands 8 or 9 feet; currents are always found near the shore.

At the village of St. Peter and St. Paul, Kamtschatka, lat. 53, 38, full and change, high water 4h. 36m. rise 5 feet 8 inches.

In the island of Onalaska, about the lat. 53, 30, the tides are said to be "*not very considerable,* except in Cook's River;" to the northward of Cape Prince of Wales, neither tides nor currents were observed. *Cook's Voyages.*

False Bay, Cape of Good Hope. The time of high water is three quarters past 2 on full and change days, and the tide flows about 6 feet.

Vandeiman's land, lat. 43, 21, high water 49m. past 6 in the morning, at the change of the moon rises 2 feet 6 inches.

Bligh's Voyages to the South Sea.

This is a sketch of the phenomenon; we will now proceed to inquire into the cause or causes, as also their mode or manner of acting.

CHAP. II.

OF THE THEORY OF THE TIDES, AS IT STANDS AT PRESENT, AND ITS REFUTATION.

1. That principle, whatever it be, by which bodies fall towards the earth is called *gravity*, and is found to extend to the sun, moon and stars; in a word, to be universal throughout the universe. It is this which preserves the rotundity and compactness of the earth; that keeps every thing in its place, and without which the world could not exist.

2. All bodies contain more or less of matter, and a small body may have more matter than a large one, on account of its parts or particles being more closely united; it is the quantity of its matter which constitutes its weight, and *weight* is only another name for *gravity;* so that all bodies gravitate according to their weight or quantity of matter; for every particle is alike indued with this property, and the gravity of the whole is no more than the sum of the gravity of the parts.

For this reason also, a large or a small body falls with the same velocity; for the large one (as a ton) is made up of small ones (as ounces) and every ounce is alike indued with the gravitating principle, and so the ton and the ounce fall equally fast, provided they fall from the same place or distance from the earth.

But if one of two equal bodies is supposed to be farther from the earth than the other, in that case they will not fall with the same velocity, but the nearest to the earth will fall fastest, and the more remote the other is, the slower will it fall.

3. Now it has been discovered and proved, that the principle of gravitation observes a particular law at all distances, which is so constant and so true, that it well deserves to be called a law of nature; which is, that as a body is removed from that towards which it gravitates, its gravity or *weight* diminishes; not as the distance, but as the square of the distance, so at different distances it is inversely as the squares of those distances.

4. It will not suit the brevity of my design, to enter into the demonstration of established truths; those who are in any manner acquainted with geometry will know this truth, and those who are not, must either take it upon trust, or refer themselves to elementary works upon such subjects.

Gravity then diminishes as the square of the distance increases, thus: suppose a particle of matter, or a drop of water, on the surface of the earth, gravitates in a certain small degree towards the moon, and another at the earth's centre gravitates also towards the moon; if we would compare the force of gravity at these two places together, we must square those two distances, and then take them *inversely;* that is, the square of the greater distance will express the gravity of a particle at the surface, and the square of the least will express the gravity of a particle at the centre of the earth, both considered as gravitating at those places respectively towards the moon; or rather, it is the *ratio* of these respective gravities which is expressed by the squares of the distances taken inversely.

Now as the moon's distance from the earth is only 60 semi-diameters of the earth, a particle at the earth's surface under the moon will be only 59 of those semi-diameters, and a particle on the opposite side will be 61; the squares of which numbers will differ considerably, and therefore the gravity of a particle of matter, or a drop of water on the different surfaces, and at the centre of the earth towards the moon, will differ considerably; and it is upon these *differences* that the present theory of the tides is founded, and I wish the reader to be very particular in attending to this point.

Let us now consider the same particles of matter as gravitating towards the sun. The sun's distance being so immensely great, compared to that of the moon, that although the gravity of any particle of matter, or drop of water on the earth's surface, is much greater towards the sun, than it is towards the moon, yet the *ratio* of the squares of the distances at the surface of the earth, nearest the sun, at the centre, and at the farthest surface, taken inversely, is much less than in the case of the moon; for, suppose the sun's distance to be 95 or 96 millions of miles, the addition or subtrac-

tion of the earth's semi-diameter will leave the number so near what it was, that the difference of the squares will be almost nothing.

If we consider the sun's distance in semi-diameters of the earth, it will be in round number about 24,000 of such semi-diameters, and it is evident that the addition and subtraction of the number 1, will give 3 numbers for the respective distances of the farthest surface, the centre, and nearest surface of the earth, the ratio of whose squares will *differ less* than the ratio of the squares of 59, 60 and 61; and so the *difference* between the gravitation of matter at the centre, farthest, and nearest surfaces of the earth is greater in the case of the moon, than in the case of the sun, although the gravitation itself is *much greater towards the sun* than it is towards the moon.

5. If we apply this principle to the waters of the ocean, we are told the whole phenomena of the tides will be explained by it.

Although I mean to combat the present theory, yet I wish to state the principle as clearly and

as distinctly as I can, and also the manner of its application for explaining the ebbing and flowing of the sea, and therefore I shall proceed to shew how this *difference* of gravitation at the centre, and at the surface, is made use of for that purpose.

Philosophers, observing that the moon goes round the earth as her centre, and the earth round the sun as her centre, and as the principle of gravitation is reciprocal and universal, the earth may be considered, they say, as going round the moon, or rather round the common centre of gravity of the earth and moon every lunation. Now this common centre of gravity will be so much nearer to the earth, than to the moon, as the matter in the earth is greater than the matter in the moon, which is considered to be as 40 to 1, and so the common centre of gravity of these two bodies is 40 times nearer to the earth than it is to the moon.

In common mechanics, when we speak of a common centre of gravity, it means when applied to two or more bodies any how connected, that

point which being suspended, the bodies themselves will be suspended.

Suppose now the earth and moon so connected together, that like two weights on a steelyard, if the fulcrum or point of support be suspended, both the earth and the moon would be suspended in equilibrio; this is the common centre of gravity of which I am speaking.

It may be easily found thus; since the matter in the earth is 40 times more than the matter in the moon, the common centre of gravity will be 40 times nearer the earth than to the moon, as was said above, therefore to produce an equation, we have only to multiply matter and distance on each side of the fulcrum or common centre of gravity.

Let the distance of this point from the centre of the earth in miles be called x, then will the distance of the same point from the moon be $240.000—x$. Now call the matter in the moon 1, then the matter in the earth will be 40; multiplying distance and matter on both sides, you will have

$$40\,x = 240.000 - x \text{ and}$$

transposing, $41\,x = 240.000$ dividing both sides by 41 $x = \frac{240.000}{41} = 5853 + \text{in miles.}$

Thus then the place of this common centre of gravity, so important in this problem of the tides, is situate a little without the earth's surface, her semi-diameter 4000 miles being subtracted, leaves only 1853+.

6. The earth goes round in this little circle every lunar month, in order to balance the moon; by the law of gravitation, that is a very little circle in a very long time. If we compare this motion or velocity with others in the system, it will scarcely deserve the name of motion: thus the earth, in turning round on its axis every 24 hours, any place under or near the equator, goes more than 1000 miles an hour, and going in her annual orbit more than 60,000 miles every hour.

Now this common centre of gravity being distant from the centre of the earth only 5853 miles, the whole diameter is 11,706, and the whole circumference 36,000, near enough for our purpose,

and so the motion hourly is about 55 miles; a motion which, compared with others, as I said before, scarcely deserves the name.

7. However, philosophers have inferred, that as the earth goes round in this little circle, she is continually falling from the tangent of the same little circle or orbit; and also they say, that *if* the earth was left to *fall freely* towards the moon, in that case the matter of the earth gravitating according to the general law before mentioned, that is to say, inversely, as the squares of the distances, the parts of the earth nearest the moon gravitating *more* than the centre, and the parts farthest from the moon gravitating *less* than the centre, there will necessarily arise an elongation on the earth's surface in the fall, the parts nearest to the moon advancing more rapidly than the centre, and the parts opposite or farthest from the moon hanging behind, and from hence say they, there will result a tide both on the side next or under the moon, and on the opposite or farthest side at the same time; and as the earth turns round on her axis in 24 hours, all places on the earth will come in suc-

cession under the moon, and so at all places there will be a tide twice in 24 hours.

8. But the philosophers go on to say further, that not only *if* the earth was left to fall freely towards the moon, such an effect would ensue, but also *if* she does *not* fall, yet the same cause which would produce the effect if she *did* fall, will still produce the effect *if* she falls *not at all.* This doctrine is far above my comprehension.

How an effect can equally ensue, whether there is cause or no cause, I have yet to learn. It does not seem to me to be sound doctrine. How can a body be said to fall, which does not *approach* that towards which it is falling? And unless there is an *actual falling*, an *actual approach*, the *difference* produced by the law of gravitation cannot take place, because it *depends* upon that *actual falling* or *actual approach* for its *cause*, and if there is no *cause*, how can there be an effect? How can an effect which is said to have *falling* for its cause, equally take place, when there is *no falling* or *no cause?* However, let us forbear a little and go on.

9. The same thing is said with respect to the sun as to the moon; the earth is considered as falling from the tangent of her annual orbit, and her parts gravitating *in the fall*, according to the general law above stated, the same effect will be produced from the same cause, only in a less degree, for the reasons above mentioned. Combining together these different gravitations, as they conspire at the conjunction and opposition of the moon, and as they retard and hinder, and cross at the quadratures, the whole phenomena of the tides has been explained.

10. I hope it will be allowed that I have stated the thing fairly, because, as I presently mean to begin to knock it all down again, I wish very much to shew first, that I know what I am about, at least, what it is that I undertake.

11. In order to be consistent, the philosophers were obliged to say, that in the equatorial regions, being the place where the particles on the earth's surface, were most subjected to the difference of gravitation so often mentioned, the tides would be most sensible, or highest, the lit-

tle table of tides in the 1st chapter shews the contrary, of which, more by and by.

One error begets another; all the calculators take care to inform us, that their calculations are for the equator; some of them make the tides rise there 11 or 12 feet; some 8 or 9—some more—some less—why they disagree, is no business of mine. But this I can say to them all—you are all mistaken—you have left nature, and bewildered yourselves and others with your fluxionary calculations, and how to make them conform to a theory which has no other foundation but your imaginations.

The tides in the torrid zone are not more than half what the calculators make them; and the half of this half, it is probable, is produced by the resistance of the *land*, against which the waters of the ocean run, so that what fairly belongs to the luminaries of heaven, is only one fourth of what has been assigned to them by the philosophers; they say, indeed, that there must be *room* for the luminaries to act, and the ocean being narrower in the torrid zone, than in the tempe-

rate, the tides on this account will be less. One does not very well see the necessity for so much room upon the principle of direct gravitation, of which so much has been said; but we will give them as much room as they like. Let them go into the Pacific Ocean, or let them sit where they are, and look into the little table of tides, what account Captain Cook and others give of the tides in that vast ocean.

"Hence it appears," says Mr. Maclaurin, in his account of Sir Isaac Newton's discoveries, "that it is only in the great oceans that such tides can be produced, and why in the larger Pacific Ocean, *they exceed those in the Atlantic Ocean.*" That great mathematician must have been very confident in his theory, when he hazarded such an assertion without proof.

They must have room they say; let them have it; in the latitude of Charleston and Madeira, the ocean is *much* wider than it is in the latitude of Ireland and Nova Scotia, yet the tides are much less.

12. I am now to make my stand against this falling doctrine, which I do upon the four following reasons.

Reason 1st. There is no such thing as the earth falling toward the moon; a falling supposes the body to be first at a *greater* distance, and after the fall at a *less* distance, whereas the earth keeps at the *same distance,* and therefore does not *fall.*

I deny that she falls *from* the tangent; she is never *in* the *tangent,* but always in the *curve.*

Reason 2d. Supposing there was a falling, in the way the philosophers say, they will gain nothing by it, as I will shew them.

Suppose then, the earth was to fall freely towards the moon, would the parts of the earth begin presently to separate? surely not, unless the gravitation of its parts towards itself was suspended or destroyed; for all the way down the fall to the very stroke of impingement, the

matter in the earth will still be 40 times greater than that in the moon, and therefore a particle on the earth's surface would not forsake a *greater* to obey a less force; for to say that a less force can overcome a greater, is not allowable.

If then, in any part of such a fall, the mutual gravitation in the parts of the earth remaining, no such separation of the parts of the earth could take place, much less would such a separation take place in the very first moment of beginning to fall.

Let us compare the gravitation of a particle of matter on the earth's surface; 1st. towards the earth itself; 2dly. towards the moon; and 3dly. towards the sun.

Call the semi-diameter of the earth 1; call also the matter in the earth 1; then the gravitation of a particle of matter on the earth's surface will be $\frac{1}{1}$ or 1. Now, as the distance of the moon from the same particle, at a mean rate, is 60 semi-diameters of the earth, and the matter in the moon only $\frac{1}{40}$ of the matter in the earth, the expression for the moon

will be $\frac{\frac{1}{40}}{60^2}$ or $\frac{\frac{1}{40}}{60 \times 60} = \frac{1}{60 \times 60 \times 40} = \frac{1}{144.000}$

lastly, the distance from the sun of the same particle on the earth's surface, may be taken in a round number at 24.000 of the same semi diameters (for we must preserve the same measure in all the cases) and the matter in the sun being taken, as it is usually taken, at 169,282 times that in the earth, then the expression for the gravity of a particle of matter on the earth's surface towards the sun, will be $\frac{169.282}{24.000^2}$ or $\frac{169.282}{24.000 \times 24.000}$, or $\frac{169.282}{576.000.000}$, or $\frac{1}{3400}$, nearly; thus we see that when the gravity of a particle on the earth's surface is considered as unity, the gravitation of the same towards the sun, is only a 3400th part of unity, and towards the moon, only 144,000th part of unity.

Now then, if the earth was actually falling towards the moon, could any body reasonably assert, that her own power of 1 would be overcome by a power of $\frac{1}{144.000}$? It might just as

well be asserted, that a person exerting the force of one pound to lift up a ton, would therefore lift it. I have never yet met with an instance of any thing being lifted up, unless a force at least *greater* than the thing to be lifted was exerted. If the earth was to fall freely towards the sun, the parts of the earth in this case *would separate*, by the law of gravitation, but not till the earth had travelled many million of miles, and her own gravitation was overpowered by the sun's greater force.

Why the moon has more power to raise the waters of the sea, or rather, why the tides follow the moon more than the sun, will appear in its proper place.

Reason 3d. If falling was the cause, or was necessary to produce by the law of gravitation, a a separation or a tendency to separation of the parts of the earth, both before and behind, the earth, at the time of full moon, would be placed in the awkward predicament of having to fall contrary ways at the same time; towards the moon, to produce the lunar tide, and towards the

sun, to produce the solar tide; a thing not to be understood.

Reason 4th. If the foregoing reasons were no reasons at all, yet this fourth would of itself be abundantly sufficient to prove, that the true cause of the tides is not rightly assigned; for if it was, the tides would *necessarily* be highest at and near the equator, or that part of the torrid zone to which the sun and moon are vertical, and decline towards the poles, whereas they are highest near the middle of the temperate zones, and decline as we approach the equator; they decline also from the temperate zones towards the poles.

Now if an effect does not correspond and agree with the cause assigned, are we not to conclude most certainly, and positively, that the cause so assigned, is not the true cause?

I might here add for another reason, if it was necessary, that if there was an actual falling of the earth towards the moon, the further surface of the earth would be *most of all* attracted, or

more correctly, would gravitate more in the direction of the moon *than any other part of the earth;* for it would gravitate in that line, at once towards the moon, and towards the earth, and its gravitation would amount to the sum of both. Now it would be very singular indeed, if those very particles so situate should lag behind; for to say that they would, would be to say that these very particles gravitating more than *any other* in that direction, that is, in the direction of the fall, yet turn sulky and will not come up so fast as others which are actuated by a *less* force; in a word, it would be to say, that the *greater* is *not* the *greater;* that a greater cause produces a less effect than a less cause, and so on.

Again, once more; supposing the earth was in a state of actual falling towards the moon, the *centre* of the earth would be influenced in *that direction* by the *moon only,* but the *farther surface* would be actuated in the *same direction* by the moon *nearly as much as the centre,* and by the whole body of the *earth* into the bargain; which, as has been shewn, is 144,000 times greater than the other, and yet we are required

to believe that those very particles will still not keep up.

If the reader is not incorrigibly obstinate, although all my reasons should fail to convince him of the fallacy of the present system of the tides, built upon the falling argument, yet if he will take the trouble to read the next chapter, he may find other collateral reasons for abjuring his error, however strongly and deeply it may have taken root in his mind.

CHAP. III.

CONTAINS AN ENTIRELY NEW EXPLANATION OF THE TIDES.

1. Having in the last chapter pulled down the fabric, and scattered about the materials, they must not however be lost, since they will serve, with a different disposition, to build it up again anew, in a manner more simple, more elegant, more noble, with juster proportions in its parts.

In order not to build upon the quicksands of fancy and imagination, I will lay the foundation upon the solid rock of experiment.

2. There are many things which seem extremely simple and easy in themselves, which yet upon further inquiry, produce insurmountable difficulties.

An instance may be this: suppose you are sitting sociably with your family and friends, and some one should say, this is a very beautiful

table, but it is *square,* and I do not admire square tables. It was on that very account that I chose it, because I know we have the same room on all sides. Yes, yes, that may be very well, but you never can know how far it is from one corner to the opposite corner, in the same measure as the sides, and that is my objection to square tables. Very strange, indeed, if I cannot, since I can measure it in a moment! Very well, do so; the side is exactly 6 feet 2 inches, and the diagonal is—how much? Now if all the men in the world, were to calculate from the beginning of the world to the end of it, they never could answer this question, simple as it might at first seem.

Another question may seem infinitely complicated and abstruse, and yet may turn out to be the simplest and most obvious, and easy, and most natural thing in the world, and such is the genuine theory of the tides.

DEFINITIONS.

3. I distinguish between *direct* gravitation and *lateral* gravitation of matter on the earth's surface, towards the sun and moon.

Definition 1. *Direct* gravitation is that which takes place when the sun or moon are in the zenith of any place upon the earth's surface, and is in the same line that any particle of matter on the earth's surface gravitates towards the earth's centre.

Definition 2. *Lateral* gravitation, I call that which takes place at 90 degrees distance from the former, or when the line of gravitation of a particle of matter, or drop of water on the earth's surface towards the sun or moon, is at *right angles* with the line of its gravitation towards the earth's centre.

EXPERIMENT I.

Fig. 1. Suspend a weight W, the larger the better; but suppose one ton, at the end of a chord A B, the longer the better, but suppose 100 feet; now suppose a person should *lift* at A with the the force of one ounce or one pound, he will not *lift* the weight in the smallest degree, yet it is very true, that if the weight W was weighed in scales whilst this force of one ounce or one pound

was exerted, the weight W, would weigh one ounce or one pound less than it did before such force acted upon it at A. Now this force at A, acts in the line of *direct* gravitation. see *Def.* 1. Observe yet more; not only will the force of one ounce or one pound, exerted at A in the line of direct gravitation, be unable to *raise* the weight W in any the smallest degree whatever, but it will be unable to give *any kind of motion whatever* to the said weight W. Let the force be exerted at *a*, at *b*, at *c*, and so on down to *f*. Now it is obvious, that whatever power it has to *move* the weight at *a*, it will have more at *b*, still more at *c*, and so on down to *g*, where it will have the greatest power of all to *move* the weight W, in the line of *lateral* gravitation W *g*.

This we see exemplified every day in drawing goods by a crane, to the different *floors* or *stories* of a warehouse, which here may be represented by the letters *a, b, c, d, e* and *f*. The least force even of a child will draw the weight W, however great, into the lowest floor *f*, but the strongest man, whilst it remains in that position, cannot draw it into any of the other floors, and *the*

higher he ascends, the less power he will have, to give any motion whatever to the weight W, and in the direction A B, he can give *no motion at all to it.*

EXPERIMENT II.

Let a wheel, no matter how large and heavy, be suspended on its axle-tree from the ground, as is done in all cases when wheels are put on, or taken off; whilst thus suspended, the least touch of the finger on the rim, if exerted in the plane of the wheel, and in a line perpendicular to any radii or spoke of the wheel, will put it in *motion,* whilst it would take the force of the strongest man so to *lift* the wheel, as to take its gravity from the axle-tree.

EXPERIMENT III.

Suppose you have a walking-stick which weighs one pound, or 5760 grains, or 11,520 half grains; take the same and balance it upright upon the floor, or if you cannot do it, conceive it to be done, (*Fig.* 3.) Now *one* of these 11,520

half grains, exerting its force in the direction *a b*, will *give motion* to the head of the stick in that direction, but the whole of them, 11,520, cannot give the least motion whatever to the stick, if their force is exerted in the direction *a c*, perpendicular to the horizon.

In a ton, there are 2240 pounds, or 4480 *half pounds*—in experiment 1. *One* of these half pounds will give *some motion* to the weight W, in the direction W *g*, but the whole 4480 cannot, if exerting their force in the direction W A, *give any motion whatever to it.*

Of the same kind is the force which draws or urges boats or ships on the water, when exerted to give motion to these in a line parallel to the horizon; but the same force, if exerted to lift them *up* or *out of the water*, would produce no effect, or rather no *motion* at all.

A pendulum is of the same kind, and the waters of the ocean may be considered as suspended like the ball of a pendulum, and as having a semi-diameter of the earth for its rod; the ball of

the pendulum being supposed to be suspended on the top, instead of hanging at the bottom of the rod, or the pendulum being considered as *inverted.*

4. We come now at last to apply this same principle to that *motion* which is produced in the waters of the ocean by the sun and moon, and from which *motion* the tides result, as their adequate and sufficient cause.

Fig. 2, *No.* 1. Let S be the sun, distant from E the earth, 24,000 semi-diameters of the earth, and M the moon, distant 60 semi-diameters of the earth from it; owing to the immense distance of the sun, there is no having a diagram with true proportions; on this account I leave S out, but it may be easily conceived to be beyond M, with a distance of 400 times E M from E. In order to give a more distinct view, No. 2 is E enlarged. Now it is evident, that the greatest effect of the sun and moon upon the waters of the ocean, *to put them in motion,* will be at *a,* and the least at *d,* where indeed it will be nothing. The waters at *a,* being suspended as it

were on a wheel, or at the end of a chord, whose length is a semidiameter of the earth, may easily be *moved laterally*, or in a line which is perpendicular to the line of their gravitation towards the centre of the earth, or *a c;* that is to say, may be easily moved in the direction *a* S, or *a* M, there being nothing to oppose such motion, but the *vis inertiæ* of the waters themselves.

The same thing may be said of the waters at O, where the same lateral action will take place, but in a contrary direction as respects the rotation of the earth on her axis; so that there will be at every place, twice in 24 hours, an impulse, one of which drawing the waters *to* the shore, will make a *tide*, and another drawing the waters *from* the shore, an *ebb*, and the *reaction* of these will produce another tide and another ebb; all this will appear more fully by and by.

It is evident also, that the water at *b*, will not be moved so easily as those at *a*, and those at *c*, with still more difficulty, and those at *d*, or immediately under the luminary, not at all; because being now in the line of *direct* gravitation, the

proper gravity of the water towards the earth's centre will overpower the other, and so no effect will ensue as to *motion*.

Again, it is evident by inspection, that the waters continue to be lateral much *longer* to the *moon* than to the sun, from her *lower position;* thus, a ray drawn from *b* to S, goes up to one of the upper floors, in experiment 1, whilst a ray drawn from *b* to M, goes to a lower floor (though not the lowest) and it was shewn, that the lower any given force acted in the set of floors, the more power it would have, and the higher the less power it would have to produce motion in the weight; in other words, the line *b* S approaches nearer to the line of *direct* gravitation, and the line *b* M nearer to the line of *lateral* gravitation, which gives the moon an advantage at point *b*, although her power is less.

Even at *c*, the moon may continue to have some small influence, whilst the sun can have none. Now as the waters at *a*, will pass successively the places *b* and c, and so on to *d*, it is evident that the sun and moon will have less

and less power over them, till they arrive at the place *d*, where it will vanish altogether.

The same thing may be said of the waters, at *x*, *y* and *z*, as they arrive in succession into the situations of *a*, *b*, *c* and *d*.

Thus it appears, that the sun's action is much greater than that of the moon, but it is continued for a very short time; the moon's action is less, but continued longer; moreover, what the sun *begins*, the moon has the advantage of taking up and *continuing;* and as it is well known that a much less force will continue a body in motion, than is requisite to put it in motion, hence, on a double account, the moon appears to have the greatest effect upon the waters of the ocean; and as her action is *last*, the tides appear to be more the effect of the moon than of the sun, though in truth the sun's force is much greater; and it will be shewn by and by, that even at the quadratures, the sun contributes much to produce the tides; and it may be questioned whether the moon, singly, and without the help of the sun to *originate motion* in the waters of the sea—it

may be questioned, I say, whether the moon could produce any *motion*, and therefore any tides at all.

5. I have pointed out the manner in which the least force, or a given force, can produce the greatest effect in giving *motion* to the waters of the ocean; and as every thing in nature is produced by the most simple law, or means, I think it follows, that this is the true way in which it is actually produced; and if *motion* in the waters of the ocean is sufficient to produce tides, we have the *simplest cause* of that *motion*, and finding that to be sufficient, we have nothing more to seek.

Now that this most simple of all modes of giving *motion* to the waters of the ocean *is* sufficient to produce the tides, I will proceed to shew.

Motion in the waters of the sea being all that is wanted to produce tides, that manner of acting to produce motion, which can produce the greatest quantity, with the least force, must be the true manner of acting in nature; for if the motion

was produced by any *other mode* of acting, yet this greatest and most powerful manner would *remain*, and then there would be *two modes* of producing it; a *less*, which is *sufficient*, and a *greater*, which *did nothing*, which is absurd; therefore this is the true way, and being sufficient, is the only one; for "*we are not to assign more causes to natural effects, than such as are true, and sufficient to explain the phenomenon.*" Rule 1, page 14.

6. Having now shewn that the motion of the waters of the ocean, from which the tides result, arises from a *lateral* and not from a *direct* gravitation, it is time to apply the same principle to explain the actual phenomenon, as we find it in nature.

PROPOSITION I.

To shew in what manner the tides on a western shore are produced.

Case 1. Suppose it to be new moon.

When the sun and moon come to, and have passed the eastern edge of the horizon of the shore (as for example, the western shore of Europe) a gravitating motion will begin to take place toward them, at first scarcely perceptible; but as it is continued every moment, it is evident that this motion will be an accelerated one, and therefore, it will become more and more rapid for some time. As the sun and moon acquire altitude, more and more water will begin to move towards the shore; the sun will act most vigorously, but for a shorter time; the moon with less force, but longer continued. The waters being thus put into motion, will run directly for the land; and by the laws of motion, a body of any kind being put in motion, will continue in motion till it is stopped by some external cause. It is evident enough in this case, that the land will stop the water; by which stoppage, however, the water will be mounted up, which we call a *tide*.

Besides the sun and moon, then there is another cause which contributes more or less to raise the waters upon the shores of the ocean, and to

produce a tide, namely, the land, against which the waters flow; and this third cause, always considerable, is in very many instances, greater than the other two put together; thus, the tides rise on the western coast of Ireland, 11 or 12 feet only, but in the Bay of Biscay, in the English Channel, and also in the Bristol Channel, according to local circumstances, they rise from 12 to 45 feet; but it is evident that the excess above 12, or rather above 6, is to be attributed to to the *resistance of the land*, and the peculiar formation of the coasts, for collecting the waters of the ocean at that particular place.

The waters, at a considerable distance from the shore, will not arrive at the shore; they will only back up those that went before for some time, till being overpowered by the accumulated waters on the shore, they will return altogether upon the ocean by *reaction*, the cause which made them run towards the land, having now ceased to act.

Suppose the sun and moon to have arrived at the meridian of the shore, and consequently, be-

ing in the line of *direct* gravitation of the waters under them, have no longer any influence upon those waters, as to giving *motion to them*, yet the waters will not cease running towards the shore; because, having been previously put in motion, that motion will continue, till it is somehow or other overpowered. In the open ocean, the waters appear, by the tide tables, to come to their greatest height about half past 2, or 3 o'clock, by which time then, it should seem, that the land had repelled the waters back towards the sea; but if that should not be the case, another cause will now begin to draw them back from the land, namely, the sun and moon, for by 3 o'clock, they will have got in a position to begin to act *laterally* to draw the waters back *from the shore* towards the sea, and this action will increase more and more, till the sun and moon descend below the horizon in the west; their acting then ceasing, the waters will return by *reaction to the shore,* and produce another tide.

The tide which was produced by the immediate impulse of the sun and moon drawing the waters towards the shore, I call the *direct tide,*

or *tide of impulse,* and that which occurs 12 hours after the former, I call the *reactive tide,* or *tide of reaction,* although, to produce this reaction, the luminaries sometimes concur more or less; for it is the same thing whether the waters are drawn *towards* the *shore,* or *from* the *shore,* since by the laws of motion, *action* and *reaction* being equal with contrary directions; it necessarily follows, that if the waters are drawn out from the land below their natural level, when the force which caused them so to ebb out, ceases to act, they will return towards the shore, and there rise above their natural level, by the resistance of the land, and so a tide must again be produced.

Case 2. Suppose it now to be full moon.

In this case, though the tide of impulse of one luminary, does not fall in with the tide of impulse of the other luminary, yet it is plain that the tide of impulse of one, falls in with the tide of reaction of the other, and this reciprocally; and therefore by the laws of motion, the sums or effects will be the same as in Case 1.

Case 3. Suppose the moon to be in the quadratures, or 1st or 3d quarters.

In this case, neither the impulsive tide of one luminary agrees with the impulsive tide of the other, or with the tide of reaction of the other; and therefore the tides will be much less than in either of the former cases.

We must not, however, conclude, that because the tide in the quadratures follow the moon, that the sun has no hand in producing them; he has still by far the greatest share in producing them.

We must always remember that the waters continue lateral much longer to the moon than to the sun, the advantage of which may be seen in Experiment 1; add to which, the moon has the further advantage of acting upon water *already in motion*, which it requires a less force to *continue* than to originate.

Supposing ourselves still upon a western shore, we must now enlarge our view of the subject.

PROPOSITION II.

To shew why the tides are not so high in the torrid zone as they are in the temperate zone, the direct contrary of what has hitherto been maintained.

Hitherto we have considered the action of the luminaries only in the direction of *east and west*, but we will now also consider the superadded action in the direction of *north and south*, and indeed in the direction of every point of the compass, and this will at once open to us the whole phenomena of the tides.

If the luminaries have more power to give *motion* to the waters of the ocean, when acting in a line perpendicular to the line of their gravitation, than when acting in the same direction as the line of gravitation, we must not confine ourselves merely to *east and west*, but consider it as taking place equally all around at the same distances.

Now if we consider that the luminaries, as they pass over the oceans of the torrid zone, can only influence the waters immediately under them, or rather the waters over which they pass, in the direction of *east and west*, being unable to bring up *in aid* any waters in the direction of *north and south*, see Experiment 1, but that the case is quite different in the temperate zone; for here not only are the waters influenced in the direction of *east and west*, but also a powerful aid is drawn by the same lateral action in a north and south direction, and this effect uniting with the other, the whole becomes much more considerable (see the table of tides.) It follows, that the tides must decrease from some latitude in the temperate zone to the line, and this is conformaable to truth. From the middle of the temperate zone, towards the north, the tides must fall off, wanting the *east and west* action, and depending only on that of *north and south*, and so they will decrease more and more, and vanish near the poles; this is also conformable to the truth.

7. We may now see that even at the quadratures, the sun has much to do with the tides; be-

cause, the moon being either before or after him six hours, she may, in either case, avail herself (so to speak) of the waters which the sun's greater force is continually putting in motion; for a body being put in motion, that motion will continue till stopped by some external cause, and therefore the moon will find those waters still in motion, and her effect will *appear to be greater* than what it is in reality, if left to herself; for this reason, as I said before, even at the quadratures, the sun has still much to do with the tides.

It may also be observed, that as the luminaries pass from east to west over the torrid zone, they can act only for a very short time on any given place within that zone, and that only in the direction of east and west, but that they can act very much longer on the polar and northern seas, even from morn to night, and therefore it is no wonder that the tides should be so much greater in the temperate than in the torrid zone.

It is for the same reason, that the tides are not greatest in the torrid zone, in that particular latitude to which the luminaries are vertical, con-

trary to what has been hitherto maintained. This fact is of itself sufficient to determine against the old theory, and to demonstrate this new one, since that old theory, built upon the falling principle, requires that the tides should be higher in that part of the torrid zone to which they are *vertical*, whereas this new theory requires just the contrary; that is to say, that the tides in the torrid zone should be highest at one tropic, when the luminaries are near the other, and this is conformable to the truth.

On January 20th, 1814, there was a remarkable eclipse of the sun; the luminaries were at that time but a few degrees from my zenith, near the tropic of capricorn; the tides were very inconsiderable; they increased till the full moon, July 2d, the same year; the moon had nearly the same declination as at the time of the eclipse, but the sun was near the other tropic. Now it would be too much to say that the moon, in this latter case, could do more by herself, than she could in the former with the assistance of the sun, according to the falling principle, but it would not at all be too much to say, that the sun could in this lat-

ter situation, give more assistance to the moon, than he could at the time of the eclipse; by Experiment 1, and its application, it could not be otherwise. And so the tide was so high as to excite much public notice at Rio de Janeiro, and was by the banks thrown up for the purpose of repressing the tides from a salina in the neighborhood, 23 or 24 inches higher than at the time of the eclipse, and this difference must be considered as immense, where the tides at no time exceed five feet and a few inches. This high tide happened in the day, as the highest full moon tides always do, on this shore. Of this, more by and by.

After having observed, for three years, in the southern part of the torrid zone, that the tides were not highest there when the sun and moon were vertical, but when they were at a distance on the other side of the zone, particularly the sun; that is, the tides are highest in the winter months, May, June, July and August, and lowest in the summer months, November, December and January. The full moon tides, however, are the highest of all about July and August. After

having observed this, I say, for three years, I sought for a corresponding effect from the same causes, on the northern part of the torrid zone, and I was not long without discovering it most satisfactorily. At Mayo, one of the Cape de Verd Islands, there is a very remarkable natural salt work. In the winter months, when the sun is far away on the southern side of the torrid zone, the tides rise higher than usual and overflow a large plain, which has no passage out again to the sea; but when the sun returns to the north, and becomes vertical to this very place, the tides are not so high; the waters of the sea do not pass over the natural bank into the plain, and those which had passed in the sun's absence, are either absorbed or evaporated, or more probably both, and leave behind a vast plain of salt ready for ships which choose to seek it there, and for which a mere trifle is paid to the Spanish governor. Thus we see the steady connexion between the cause and the effect.

8. Having now dispatched what relates to a western shore, it remains to say something of an

eastern shore, and here we shall find a difference most extraordinary and curious.

PROPOSITION III.

To shew how the tides are produced on an eastern shore, and why they are less on the shores of America, than on those of Europe and Africa.

Case 1. Suppose it to be new moon.

When the luminaries rise upon an eastern shore, they will draw the waters *from* the shore and produce an *ebb*, but as the luminaries acquire altitude, their force will decrease more and more, till it will vanish when they are in the meridian of the shore, at which time, or soon after, the waters will return by reaction ; and if we suppose this to be the first time, a small tide will be the result of this reaction. In the afternoon, as the luminaries descend towards the west, they will draw the waters towards the shore, and their greatest action being at sunset, the waters being put in motion, must have time to arrive at the shore ; for as the motion in the waters is only four or five

miles an hour, it will take six hours for the waters even at the small distance of 30 miles, to come to the shore, and so it will be midnight before the *tide of impulse* on an eastern shore will be at the highest; after which they will ebb out, and when the luminaries rise again in the morning, their force will be to check the second reaction which will be taking place, and so the regular swing, oscillation or play of the waters will be interrupted; and on this account they will not rise so high upon the land.

On a western shore, the greatest force of the luminaries takes place *first,* i. e. when they rise in the horizon, but on an eastern shore, the greatest force takes place *last,* i. e. when they set in the horizon; the consequence is, that there is a difference of nine hours on the two shores, betwixt the time of the luminaries passing the meridian, and the time of high water there; and therefore on an eastern shore, as that of America, the luminaries get round again, not to assist the *reaction,* as on the other shore, but to interrupt it; and the tide of reaction being interrupted, the

tide of impulse will also be affected, and thus upon the whole, they will not rise so high.

Observe, however, that this irregularity relates only to the motion of the waters in an *east and west* direction, that in a north and south direction not being so much affected by it, hence the effect of this want of co-operation will be most sensible in the torrid zone; and accordingly, there are within the torrid zone, and especially that particular part of it where the luminaries are, but little tides.

Case 2. Suppose it to be full moon.

When the sun has descended below the horizon in the west, and has just exerted its greatest force upon the waters, the moon rises to oppose that force with her force, and so the impulsive tide of the sun at midnight will be interrupted and lessened; and when the moon has descended below the horizon in the west, and has just exerted her greatest force upon the waters, the sun will rise to oppose that force, and so the impulsive tide of the moon at mid-day will be inter-

rupted and lessened; yet as the impulsive tides of one luminary agree and fall in with the reactive tides of the other, the interruption or lessening upon the whole is not more than at the new moon, though at first sight it might seem as if the opposing forces would entirely extinguish each other. Let it be remembered also, that this interruption, as in Case 1, relates only to the motion of the waters in an *east and west* direction, and therefore the effect is most sensible in the torrid zone, and more especially in that part of it where the luminaries are.

Case 3. Suppose the moon to be in either of the quadratures.

In this case, the irregularities continuing, the luminaries will lose that co-operation which they had, *being together*, in Case 1, and that agreement of impulsive with reactive tides which took place in Case 2; and therefore the effects will be less than in either of those cases. Accordingly, by the table, the tides are less on the whole coast of America, and within the torrid zone, and more especially that part of it where the lumi-

naries are, they are almost nothing. By the old theory, they ought to be higher here than in any other place; because, beginning on the eastern side, and rolling on progressively to the west, and not being able to advance further for the land, they ought here to accumulate in a more particular manner, and their not doing so is another reason amongst so many, that that theory has no foundation in truth; for in explaining effects from their causes, nothing must be overlooked; every part must agree, and nothing disagree; for without this, it is either not well explained, or not well understood, or entirely without foundation.

9. I intended to confine myself to the seeking only of the general principle, but I find some local circumstances of so much importance, that they cannot well be omitted. Two circumstances which may be called local, deserve particular notice. One of them goes to increase the European tides, and the other to diminish the American tides. It is well known to mariners, that there is a powerful current always setting along the coast of Norway, for the south, and these

northern waters, being thus already in motion, the effect of the luminaries will be much greater upon them, than if there was no such motion already begun. Now the *cause* of this current is most obvious; all the rivers of the north of Asia disembogue into the northern sea; and that sea having no other outlet for the waters to return to the great oceans, this current must of necessity take place. The tides throughout all the British seas, are increased by this local circumstance. Behold here also the polar effusions of St. Pierre.

On the coast of America there is no such thing; nay more, there is a local circumstance which tends to lessen the tides there, namely, the *gulf stream.* This remarkable phenomenon, issuing from the gulf of Mexico, and not far from the American shore, widens from the land as it advances northward, and is yet sensible off the banks of Newfoundland. Now it is very evident, that the tides upon that shore, will be retarded and lessened by that powerful stream interfering with the action of the luminaries, and so we find the tides smaller than on the European side, on

this account also; and by the table, it appears that the time of high water is much later, namely, seven o'clock, which must be understood for seven in the morning, for the tide of impulse at new moon, and seven at night for that of full moon. At Rio de Janeiro, the new and full moon tides take place at 2h. 30m. at the entrance of the harbor; ten miles within, owing to local circumstances, they take place at the same time, and this is the place of my observations.

Here uniformly the *night* tides at new moon are highest, but at full moon, on the contrary, the *day* tides are highest.

Now if this gulf stream should so interfere with the action of the luminaries, as to prevent them giving more motion to the waters of the ocean than $2\frac{1}{2}$ miles per hour, it will take 12 hours to bring the waters at the distance of only 30 miles to the shore, whilst they will advance the same distance in six hours, at the rate of five miles per hour, where there is no such impediment; and advancing slower or with less force, they will not only be later, but *less*.

That the tides in the Pacific Ocean are less than in the Atlantic, is most plain, there being no northern seas, much less a Norway current to be acted upon, in aid of the merely east and west action.

Finally, combine the local circumstances with the general principle, and you will have the solution for any particular place.

10. Spirit of Newton! what sayest thou? rejoice with me, for that an error is detected, and a new truth established in thy favorite walk. Tell me, great spirit, if the direct attraction was true, would this more powerful lateral action be at liberty to be overlooked and neglected?

The wisdom of providence, or rather of the Deity, is manifest in placing the luminaries at such exact distances, that their action, in the cases where they can most act on the particles of the others, shall only produce such moderate effects, as correspond with the ordinary course of things; thus the rivers are made to run back, at the same rate as they flow, and no particular

care is requisite to guard against the impetuosity of the tides; but if the tides could be produced by a direct action between the luminaries and the waters of the ocean, then doubtless, the lateral action would be so much greater, as to deluge the world.

In the Newtonian theory of the tides, the moon is considered, from her lower position, as having a greater power to move the waters of the ocean than the sun, and yet all astronomers know that the earth, and every part of it, gravitate *much more* towards the *sun* than towards the *moon*. This contradiction arose from taking the tides, at the full and change, as the *sum*, and at the quadratures, as the *difference* of the effects of the sun and moon upon the waters of the sea; instead of seeking the cause, from the effect truly observed in all latitudes, and particularly within the torrid zone, the cause and its manner of acting was *assumed*, and then such effects were deduced from it, as would naturally follow such an assumption; but when we find that these effects are not those of nature and truth, the assumed

cause, or its manner of acting, necessarily falls to the ground.

The tides may be said, in a few words, to be the effect of the lateral gravitation of the waters of the ocean towards the sun, modified by the gravitation of the same waters towards the moon, according to her position with respect to any given place, and are greatest at that place, at the full moon, when the sun is distant north or south about 45 degrees (if that can happen, because at this distance, the sun's action in an east and west direction, can unite with his action in a north and south direction, with the greatest effect) and the full moon falls between the sun and the place. If the sun's distance cannot be 45 degrees from the place, then the greatest tides there will be, when the sun's distance is the greatest that it can be, and the full moon falls between the place and the sun.

If the full moon cannot fall between the sun and the place, when the sun is 45 degrees from it, the highest tides at that place may happen when the sun is more distant than 45 degrees,

and the moon is full, as in the British seas, where the highest tides happen *before* the vernal and *after* the autumnal equinox, at full moon; because then the moon falls between the sun and the place, and is more favorably situate for acting upon the waters which have been put into motion by the greater force of the sun.

It may happen that the new moon tides are higher than the full moon tides, as is the case in the summer in the British seas, because the full moon is too far off at this season, to act upon the waters put into motion by the sun, especially in an east and west direction, which is her peculiar office in producing tides. She may be called the sun's handmaid in this business.

With regard to the difference between day and night tides, I suppose it will happen every where as I found it in the torrid zone; namely, that the *impulsive* tides will be somewhat greater than the *reactive*, the latter being a little lessened by friction: thus, in Europe the day tides at new moon, and especially in summer, will exceed the night tides, and the night tides at full moon, and especially in winter, will exceed the day tides.

According to the Newtonian account of the tides, we are told that they are highest when the sun and moon are in or near the equator. Where are they highest? at the equator? certainly not—at the tropics? no, certainly not—where then, at Bristol? yes—but how does it happen that the tides are not highest at Bristol, when the sun and moon are acting together in the northern tropic, $23\frac{1}{2}$ degrees nearer to Bristol than they were at the equator?

If the sun and moon were to decline so far as to become vertical at Bristol, do they not mean to say, that the tides would, in that case, be much higher there than they are now, when the sun and moon are in the equator; otherwise, what will become of the direct influence of those bodies upon the waters of the ocean? Now as the tides are *not* so high at Bristol, when the sun and moon are in the northern tropic, so if they were to decline as far as Bristol, the tides would grow less and less at that place, and be no more (leaving out local circumstances) than they now are at places within the torrid zone to which the sun and moon are vertical, that is, about three feet,

which is what I found them at the southern tropic in the month of December.

Let the philosophers consider all this, and if they can reconcile so many absurdities and contradictions to the old theory, let them do it; but if they cannot, let them give it up with a good grace.

11. Drawing near to a conclusion, I shall here introduce another quotation from that excellent mathematician and philosopher, Maclaurin, who, in his account of Newton's discoveries, makes this observation upon Aristotle and his philosophy, namely, that he was for a long time called the prince of philosophers, and possessed the most absolute authority in the schools. "His opinions was allowed to stand on a level with reason itself." Continues he, "it is not improper to have this slavish subjection of philosophers in remembrance; because a high esteem for great men, is apt to make us devoted to their opinions even in doubtful matters, and sometime in such as are foreign to philosophy."

I will add for myself, that if a divine being was capable of errors in matters of science, they ought not to be respected, much less those of mortals.

The particular observations which I may yet make near the southern tropic, as well as in other parts of the world,* will be given in a future edition, if the public curiosity should call for them; if not, I shall rest satisfied with having given the general principle, and a few of the most important local circumstances by which the tides are influenced.

* This was written in 1813.

Rise, Newton, rise! for thyself speak aloud
Nations on Nations have join'd in the croud
T'oppose

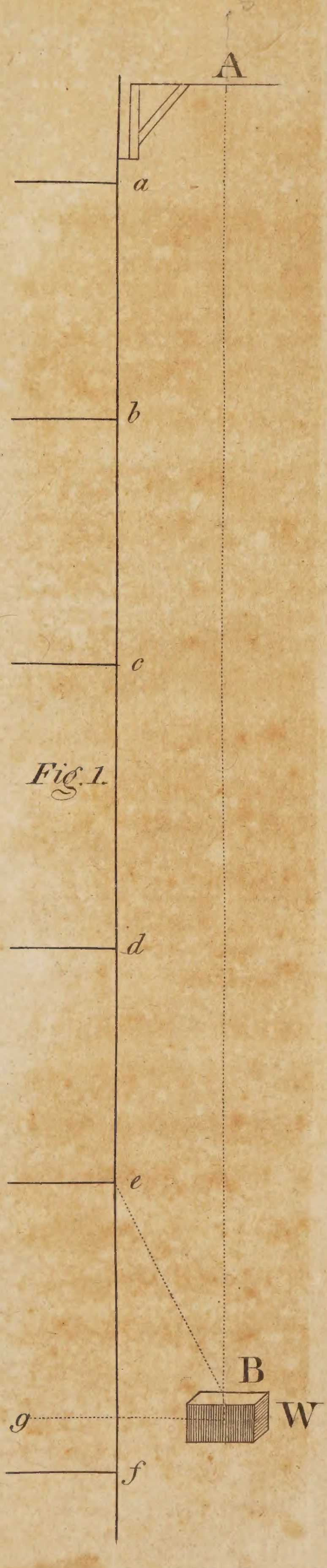

Fig. 1.

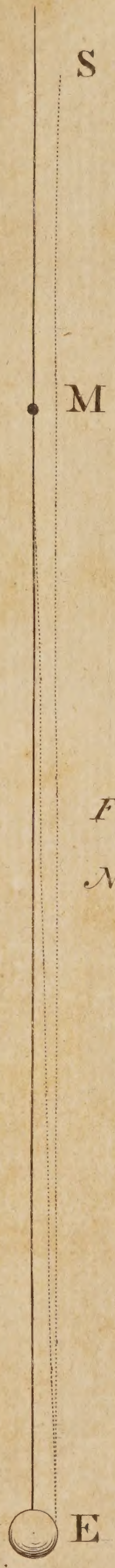

Fig. 2.

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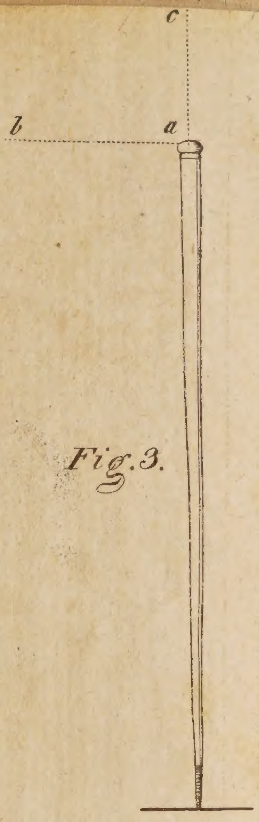
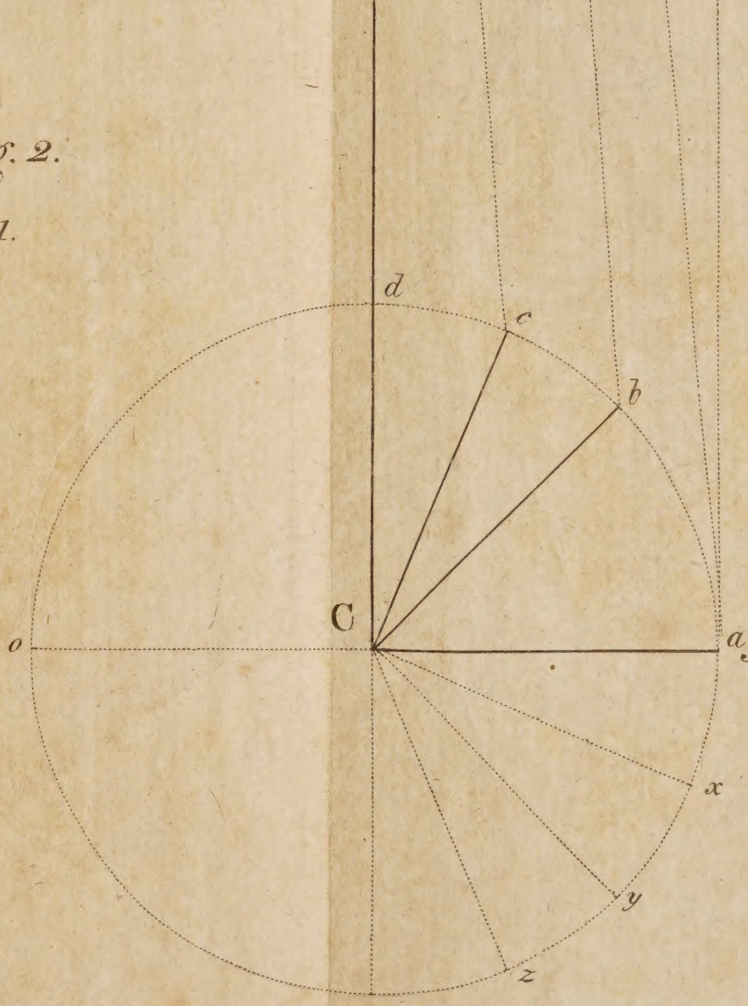


Fig. 3.



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Mr Thomas P. Irving

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